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Packet Radio Temporary Note 14

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PACKET RADIO PROPAGATION CHARACTERISTICS

The purpose of this note is to raise some issues relative to Packet Radio transmission by a more explicit treatment of path loss and channel effects than were put forth in Mr. Cory's note NIC #13483. These effects enter into power budget considerations as mentioned there, but they also bear heavily on frequency selection and modem considerations. It is very difficult to generalize in a model all the important situations regarding specific path and channel effects. One is compelled to either treat specific topics such as multipath, local diffraction, etc. and run the risk of improperly emphasizing a single aspect out of the total system context or else providing initially a narrative oriented discussion which keeps the prespective but is too subjective for the curious reader. The latter treatment is given in this note with just enough detail to focus on the issues and the calculations supporting the conclusions drawn from them. A further restriction for this net is consideration of radio in populated environs as opposed to including both "commercial" and tactical military usage, the latter including usage of terminals immersed in foliage or perhaps air-dropped and unattended.

The issues, simply stated, include the following:

1. There are compelling reasons based on path consideration to choose as low an operating frequency as possible for all path categories and almost no reason for going high in frequency, save, perhaps, for obtaining adequate channel capacity in city environments with attendant density of frequency assignments and probably higher "noise".

2. The choice of omnidirectional antennas in city areas for both repeaters and terminals limits both the highest practical frequency due to decrease in physical aperature with increase in frequency and also the maximum signalling rate due to the greater observed multipath.

3. The density of repeaters must be substantially greater in urban areas than in suburban or rural areas to provide an adequate operating network grid.

4. There is a distinct difference in path "design methodology" between trunking type point-point microwave radio links and the radio links for packet radio communications, the later being more akin to the land mobile radio services.

SUMMARY

Long-haul trunking is the term used to describe the traffic carried between major population centers. It is expected that traffic density will be extremely high with data rates in the tens of megabits per second. High reliability will be required from the standpoints of bit-error rate and of time-availability.

The maximum distance between repeaters on the basis of communication between them is about 17 miles for 30 meter antenna heights. The quasi-smooth path loss at such a distance is -146 dB at 500 MHz and increases at 6 dB per octave to -173 dB at 12 GHz. This and other considerations will limit the repeater-to-repeater communications to frequencies less than 10 GHz. The 17-mile spacing is based on the LOS distance and is valid only for sparsely (user) populated areas where the terrain is fairly smooth. In a city where many tall buildings serve as multipath reflectors causing channel distortion, the repeaters must be spaced much closer together, 3 to 10 miles apart to maintain circuit integrity. Of course, the greater density of terminals in a city would require a greater density of repeaters regardless of the ability of the repeaters to communicate with each other.

Of all the situations possible in the terminal-to-repeater link, the limiting case is when the two ends of the link are inside a city. The median signal may be as much as 50 dB lower than one would expect of the same terminal-to-repeater path length in a rural location. There are virtually no direct path communications in the city. All the signals are reflected around buildings or diffracted over the tops of buildings. Every data bit is accompanied by echoes for 4 to 12 microseconds. This will limit data rates

to bit lengths no shorter than 8 μs; reliability would be markedly improved by using even longer bits. Assuming 1 bit/Hz, the signalling rate will be limited to about 100 kb with 25 kb perhaps being a practical goal. Man-made noise is a factor which adversely affects the urban terminal-repeater link. However, the multipath problem would probably set the irreducible bit error rate. From these, and other factors, the urban terminal-repeater link will be limited to less than three miles; the frequency will be less than 2 GHz, and the signalling rate will be about 25 kilobits per second. For simple knife edge diffraction around the edges of buildings, the added path loss with respect to free space is about 10 dB for a decade increase in frequency per bend in addition to the assumed 20 dB/decade increase in loss with increase in frequency due to using simple constant-gain omnidirectional antennas.

GENERAL DISCUSSION OF PROPAGATION PROBLEM

Reliable radio propagation at frequencies higher than 40 MHz is limited to less than the line-of-sight (LOS) distance. Within the LOS, there are several types of propagation paths which can create a variety of received signal characteristics. In general, the communicator finds himself in a field of standing waves. They may have shallow nulls or deep; they may be stable or slowly moving; or the communicator himself may be stationary or moving through this field of standing waves. Adjacent nulls may be spaced as close as half wavelength intervals and may take the forms of points, lines, or planes in three dimensional space. If both the communicator and the field are stationary, one simply moves a short distance until this antenna is in a field maximum and the problem is minimized. If either are moving, then one must accommodate himself to an interfering modulation of his signal by the propagation medium. At almost any range under any condition the propagation medium will place finite limits on the bandwidth that can be used and the bit-error-rate than can be achieved.

For ease of discussion, the writer has divided the types of LOS paths into three categories. The first considers the generally short paths between terminals and repeaters where the user terminal is assumed to be at low height with respect to surrounding terrain with the repeater assumed to be located at some modest height, say 30 meters, somewhat akin to the land

mobile service. The second considers the short to moderate length paths between repeaters, say 6 miles or so, where the antennas are both at modest heights over average terrain. The third, which is kind of a reference case and is treated only briefly, considers longer distance trunking akin to common carrier point-point microwave links.

The user terminal equipment is conceptualized as a small portable radio. It may be hand-held, desk mounted, or installed in a vehicle. It may be battery operated and consequently low powered. The antenna must be small so that it could be a part of a hand-held unit. It must be omnidirectional. We are assuming that if the terminal is inside a building or car, that he at least has an outside antenna, and possibly, in the case of a building, a repeater which might gather several signals from inside and transmit the data from a rooftop.

The repeater path characterization has some obvious differences from the terminals. The transmitter is not limited in power as is the terminal radio, and the antenna will be mounted on a tower. The antenna will be omnidirectional but may have some gain by narrowing the elevation plane beamwidth. The tower may be about 30 meters tall. This height is practical for several reasons. It can "see" a greater range than a battery powered radio can reach from the considerations of its power budget.[1] The tower needs to be economical as a considerable number of them will be required. The distance covered by a tower is proportional to the square root of the height of a tower, but the cost of the tower, guys, and land are roughly proportional to the square of the height.

SPECIFIC PATH CONSIDERATIONS

Line of Sight. It is common to refer to the radio horizon of line-of-sight (LOS) as calculated geometrically with the tower heights on a curved earth of 4/3 the true earth radius. This LOS distance can be calculated handily by

$$d = \sqrt{2(h_t+h_r)} \text{ miles}$$

where h_t and h_r are the transmitting and receiving antenna heights above the average terrain, measured in feet. Collins Radio Company uses a more conservative distance by using the true earth radius, reducing d by 0.866.

With this conservative stand the 30-meter antennas might be as far apart as 16.8 miles unless there is a compelling reason for closer spacing due to multipath, path loss, etc.

Path Clearance. In addition to establishing a shorter LOS in the interest of increasing reliability, the path of the optical ray must clear large obstacles on all sides of the array by at least 0.6 of the Fresnel zone radius.[2]

$$R_f = 550\sqrt{\frac{d_1(d-d_1)}{d\,f}}$$

d = path length in kilometers

d_1 = distance along path to measurement point (km)

f = frequency in MHz

For example, if the path was to go close by a hillside 10 km from one terminal on a 15 km path length and the frequency was 1000 MHz, then the geometric center of the path should clear the mountain by at least 31.7 meters.

Path Loss. What kind of transmission loss might one expect on such a path? Field strength is not a function of frequency in clear-shot situations so it is most convenient to calculate the field strength for an assumed power level and compare it to the free space field strengths, taking the difference as the loss over free space loss. C.C.I.R. Recommendation 370-1[3] has curves of measured field strengths at various distances for 1000 watts radiated from a dipole ($G = 1.637$). An emirical equation which compares closely with these curves for low heights and short distances is:

$$E = 113.2\,\frac{(h_1+h_2)}{d^2}\sqrt{\frac{P_tG_t}{d}}$$

H_1, h_2 = Transmit and receive antenna heights (meters)

d = distance (km)

P_t = transmitted power (watts)

G_t = transmit antenna gain factor

Free space field strength is calculated from

$$E = \frac{10^3\sqrt{30\,P_tG_t}}{d}\ \mu v/m$$

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Of course, at short distances and for tall antennas, the empirical formula might give a higher value for E than the free-space formula, in which case the latter should be used. To get from field strength to received power, one must calculate the power density of the field times the effective aperture of the receive antenna.

$$W_r = \frac{E^2 \times 10^{-12}}{120\pi} \times \frac{\lambda^2 G_r}{4\pi} \text{ watts}$$

λ = wavelength in meters

G_r = receive antenna gain factor

E = field strength (μv/m)

These calculations are all for the median value; 50% of the receive locations, 50% of the time in suburban or slightly rolling hills. The statistical nature is that as one approaches the LOS, the time variability approaches a Rayleigh distribution. Location variability is also Rayleigh over a small area but becomes log-normally distributed over larger areas.

Path Perturbations. Most long-haul microwave paths experience some degree of fading. They have "fast-fading" caused by multiple signals arriving from scatterers off the main optical axis of the path. These scatterers may be areas of temperature gradients in the atmosphere which change the dielectric constant of the air and cause refraction of the waves. A slower fade might be from a single specular reflection as from a body of water at mid-path. That situation is one to be avoided! Fades caused in this manner can be 40 dB deep and last for hours. Most types of fading (there are many) are characteristic of long-haul circuits. With tall towers on mountain tops they commonly reach 80 km on a path. Our repeater-to-repeater scenario with 30-meter antennas is limited to less than 30 km path length. The writer has not seen any data which describes fast fading at such short path lengths. Most of the published data on fading was taken with narrow beam antennas and may not be valid for omnidirectional antennas.

Most microwave point-to-point system design manuals recommend adding 30 to 40 dB of system gain as a fade margin. These systems require a high degree of time availability. Figure 1 shows fade margins vs. time availability

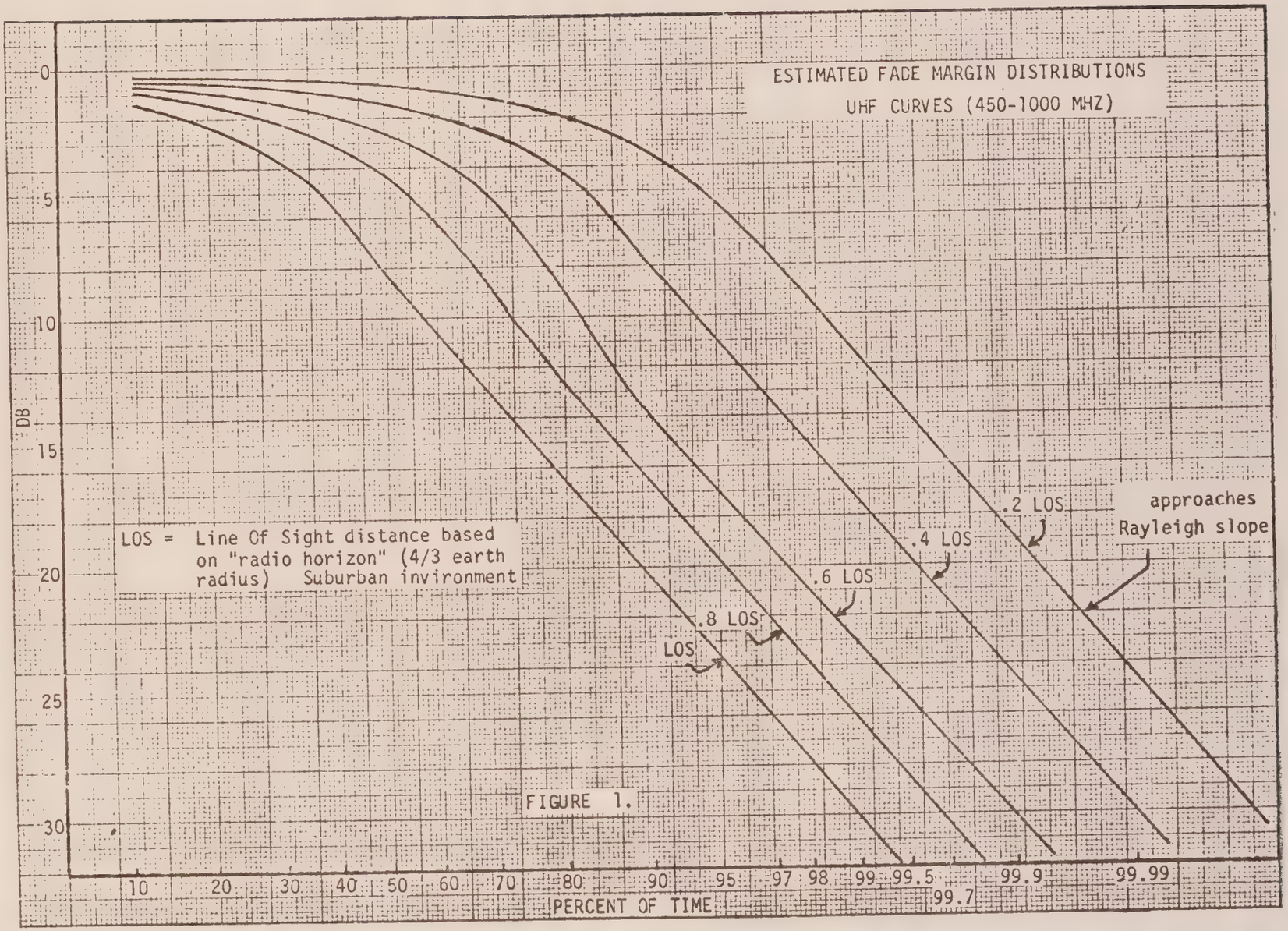

ESTIMATED FADE MARGIN DISTRIBUTIONS
UHF CURVES (450-1000 MHZ)
DB
0
5
10
15
20
25
30
LOS = Line Of Sight distance based on "radio horizon" (4/3 earth radius) Suburban invironment
.2 LOS
.4 LOS
.6 LOS
.8 LOS
LOS
approaches Rayleigh slope
10
20
30
40
50
60
70
80
90
95
97
98
99
99.5
99.7
99.9
99.99
PERCENT OF TIME

FIGURE 1.

for distances normalized to the LOS[4]. These curves were prepared from measured data presented in CCIR Recommendation 370-1. The Bell System telephone network is designed on a time availability of 90%; on long distance calls, one should find all trunks busy 10% of the time. This is probably not unreasonable for the packet radio concept. With cell structured hub patterns, the hubs are located at .8 LOS, so for 90% time availability, only 16 dB of fade margin is required. Most microwave point-point system design manuals recommend adding 30 to 40 dB of extra transmitter power as the fade margin for time availabilities in 99.9-99.99 percentiles. Properly designed space diversity, two receiving systems working together can reduce the fading threat by 5 to 10 dB. They are usually located at different heights on the same tower.

MULTIPATH VS. ANTENNA GAIN

For LOS microwave paths in rural or suburban areas and employing substantial antenna gain (35-45 dB) multipath does not play a significant role in the median system performance. The primary multipath source for these high-gain systems is reflection from stratified air layers having fairly well defined boundaries in refractive index due to temperature gradients. The path signalling rate is not limited in these circumstances, nor is the error rate; however, for circuits requiring time availability such that outages of only 1-10 hours/year are permissible, fading margins of 30-40 dB are added.

For LOS paths employing omnidirection (or at least widebeam) antennas, the significance of multipath is much greater. Additional sources include discrete reflections in the immediate vicinity of one terminal, transverse reflections from objects in the antenna beam at greater range, and finally "background scatter" or generally incoherent scattering from objects spread out on an asymmetric topography.

Several aspects of multipath are worth mentioning early in this note:

(1) For fixed-location terminals, multipath effects are carrier frequency independent, but are signalling rate dependent.

(2) Multipath in the immediate vicinity of terminals can often be mitigated against in a fading sense by moving the antenna a half-wavelength or so, but probably not for a wide sector of coverage angles.

(3) Even though the "close-in" multipath is mitigated against from a signal level point of view, the existance of the multipath will still limit the maximum signalling rate which can be used.

(4) Insofar as modem performance is concerned, the irreducible error rate (beyond which no increase in signal level will improve performance) does not require strictly equal amplitude "interferors"' but there can be a spread of 10-20 dB in amplitude over which the influence of a weaker reflection can be important.

(5) The significance of multipath becomes less as the antenna gain is increased.

In semi-rural areas, transverse multipath levels of several 10ths of a microsecond are to be expected. For long suburban paths (of the order of 10 miles or so), a microsecond or two can be expected. In urban areas, shont paths (1-3 miles) will exhibit 1-2 microseconds on average; and for longer paths, 5-7 microseconds are not uncommon.

Figure 2 shows the relationship of irreducible error rate vs. amplitude ratio (assuming two interfering signals, one deterministic and the other varying) assuming QDPSK modulation (after Fralick, SRI, liberally interpreted) for discrete value of the time delay to bit period ratio. For transverse multipath, an estimate of median fade depths (from which amplitude ratio can be derived) can be obtained as the difference between the 1% and 50% curves for land in CCIR Rec 370-1. Furthermore, it is appropriate to normalize these to a percentage of LOS distance due to the ease in visualization achieved. My estimate of amplitude ratio vs. LOS distance is given in Figure 3. Employing these data with the angular discrimination of a directional antenna radiation path (equal to $2J_1(u)/u$ for uniformly illuminated dish antennas) permits calculation of maximum signalling rate (1 bit/Hz) vs. antenna gain for a given BER and delay time. Curves for .1 and 1 microsecond delays are shown respectively as Figures 4 and 5.

Considering incoherent scatter, with a 10-mile path employing 100-foot high antennas and an average coherent scattering element sized to the specular Fresnel zone area at mid-paths @ 7500 MHz and 35 dB antenna gain, the

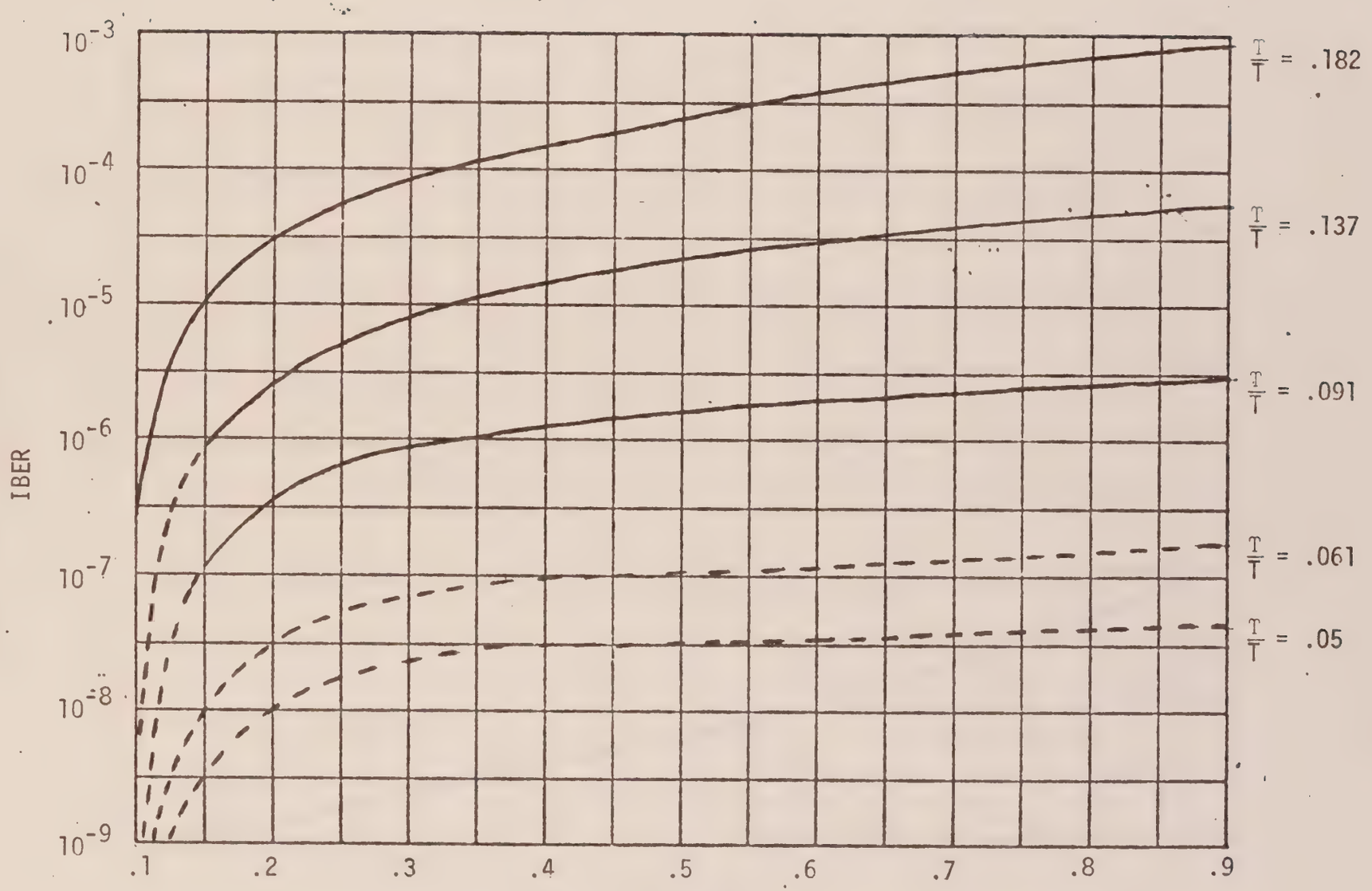


FIGURE 2

MULTIPATH CRITERIA BASED ON
QDPSK KINEPLEX MODEL

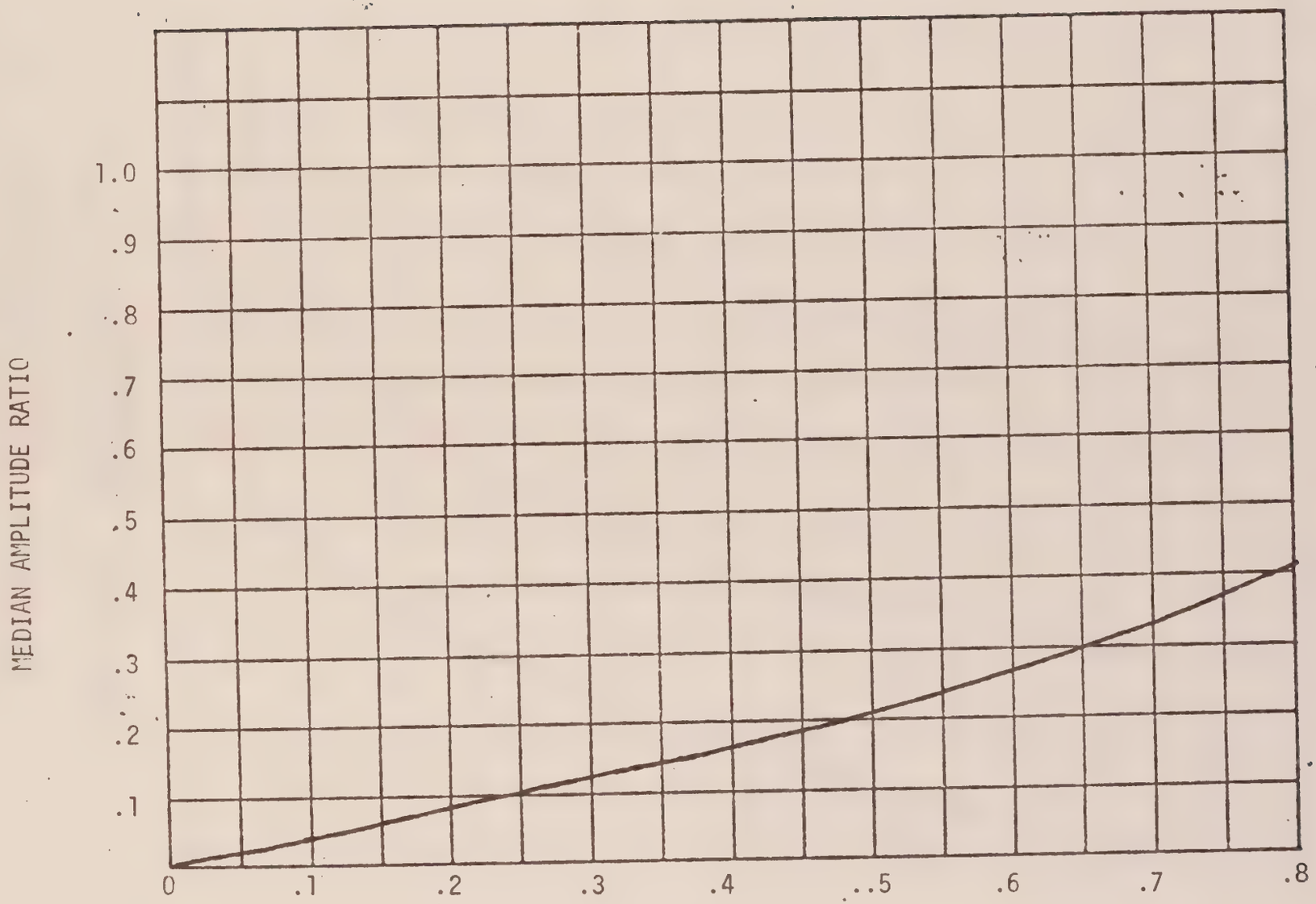


FIGURE 3
AMPLITUDE RATIO VS. NORMALIZED LOS DISTANCE
DERIVED FROM CCIR RECOMMENDATION 370-1

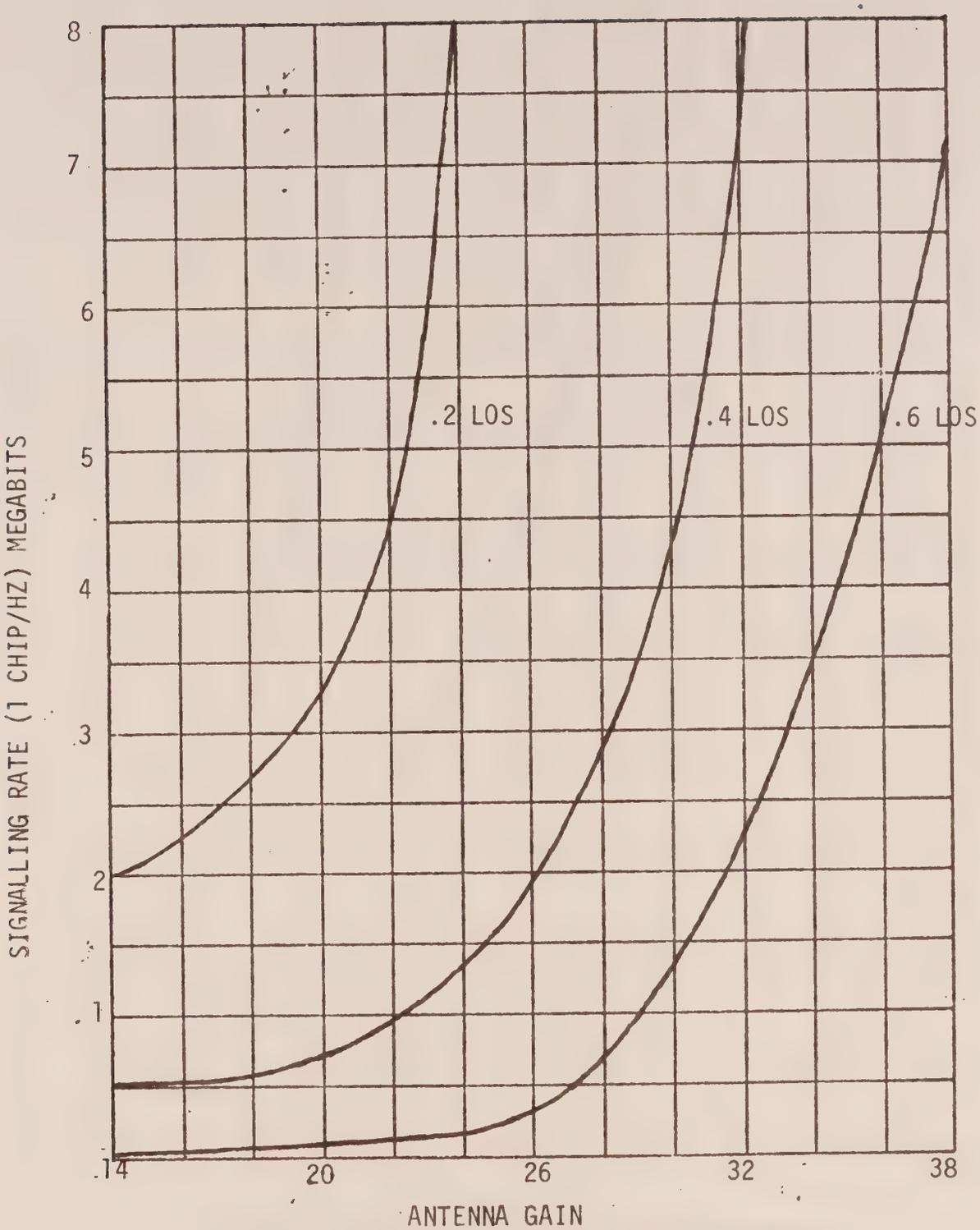


FIGURE 4
UPPER BOUND ON SIGNALLING RATE DUE
TO DISCRETE MULTIPATH OF 10^{-7} SECONDS
FOR AN IBER OF 10^{-6}

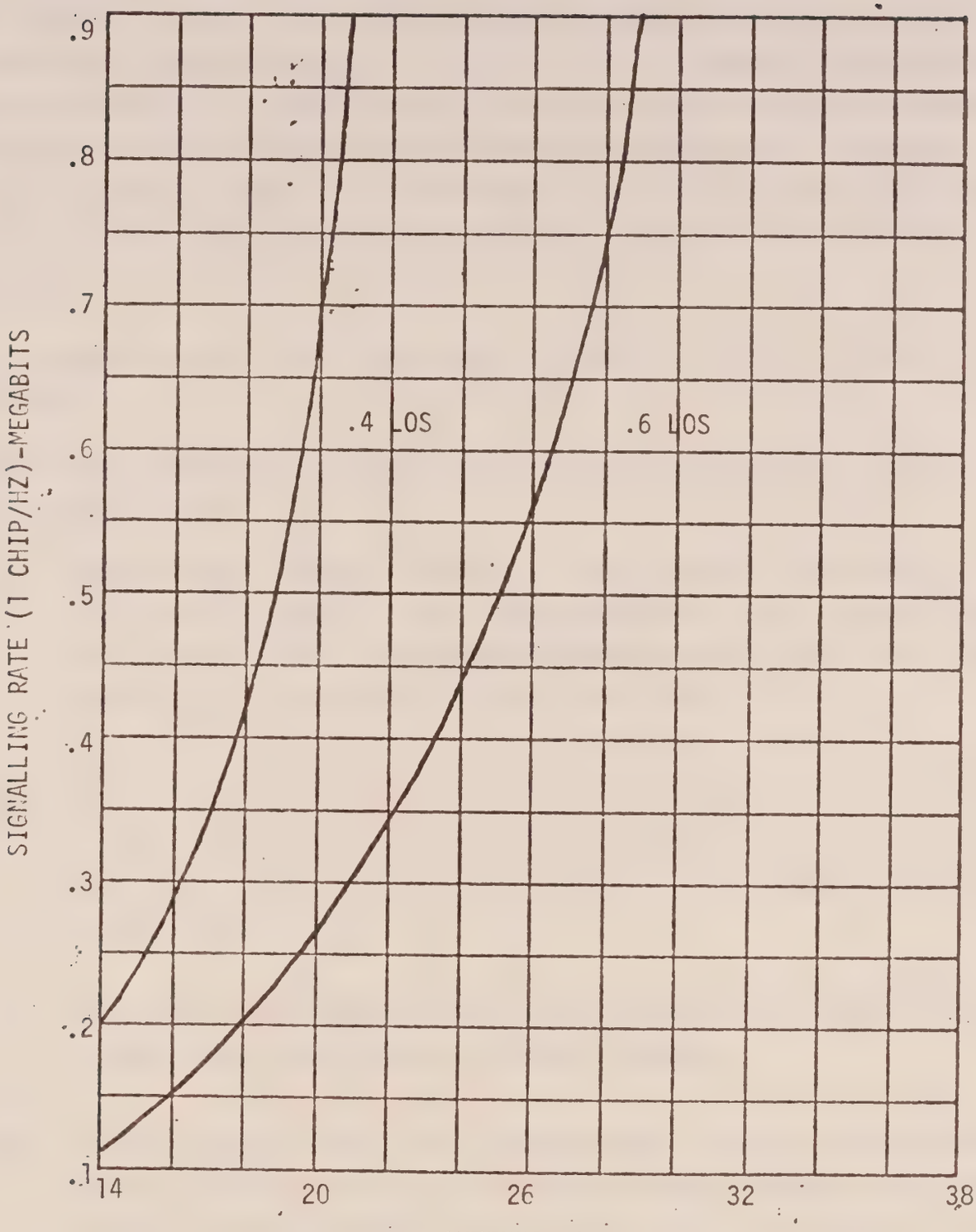


FIGURE 5
UPPER BOUND ON SIGNALLING RATE DUE TO DISCRETE MULTI-PATH OF 10^{-6} SECONDS FOR IBER OF 10^{-6}

scattered field is down 24.5 dB. The incoherent scatter floor will likely never produce a change of more than about 3 dB from the 24.5 (or 16.5 dB) corresponding to an amplitude ratio of .14. If an "asymmetric scattering center" is defomed as at mid-path and located half the transverse distance to the edge after scattering zero (as defined by the antenna 3 dB beam-widths) the delay is about $.2 \times 10^{-8}$ seconds and is likely near greater than $.5 \times 10^{8}$ seconds. For a 10 megabit signalling rate, the error rate floor is at 10^{-9}.

So... incoherent scatter is likely never a serious problem at microwave frequencies.

The following specific conclusions can be drawn with respect to discrete transverse multipaths:

(1) For multipath delays in excess of 1 microsecond, the antenna gain (assuming equal E and H plane beamwidths) must exceed 20 dB on a 6-10 mile path with antennas mounted at 100 feet for a signal-ling rate of 1 megabit (1 chip/Hz) @ 10^{-6} BER.

(2) The variation of signalling rate with antenna gain is not linear as, for example, on a 10-mile path for conditions of (1) above, a 6 dB drop in antenna gain will drop the maximum signalling rate by a factor of 5.

(3) Using omnidirectional antennas on the same 10-6 mile paths give maximum signalling rates of 100-200 kilobits.

(4) For very close "shots" with high mounted antennas, multipath may not be a problem even with wide beam antennas; however, for short heights as typical of the land mobile service, multipath will be a problem even at close range.

SPECIFIC TERMINAL - REPEATER CASES

General. This scenario is pictured as a 30m antenna communicating with ubiquitous users providing them with a reliable exchange of data at all times. It is the weakest link in the packet radio system from a propagation standpoint. In the repeater-to-repeater situation one can say "allow a 30 dB fade margin". But you can say to a ni-cad battery "Give me one thousand times more peak power?"

In order for the system to be reciprocal, the hub or repeater must provide a decibel of receive antenna gain or receiver sensitivity for every dB of power advantage its transmitter has over that of the user. Increasing antenna gain for an omnidirectional antenna means narrowing the elevation plane coverage. This would provide the greatest benefit in open, flat country.

The terminal-to-repeater links can be classified into three groups, rural, suburban and urban. A discussion of each might be in order.

Urban Terminal-to-Repeater. The urban class was selected to be presented first for two reasons. One is that it will be the limiting case for data rate, and second because Okumura[5] and his associates presented it in their paper. Their work shall be used here exclusively for field strength estimates in the terminal-to-repeater links. They have done a very thorough work, and the curves in this section are taken from that report.

Figure 6 shows median field strengths for three frequencies and two transmit antenna heights. The receiver antenna height was always 3 meters. The transmitted power was 1 kW from a dipole (1 kW erp). Using these curves and working Mr. Cory's paper, we can calculate some maximum ranges for three frequencies in the urban environment.

We might assume a one-watt hand transmitter with a dipole antenna at the user end of the link, and an eight element vertical collinear array at 30 meters high at the terminal receiver (11 dB > isotropic). If the required received power is -133.2 dBW, and the gain is 11 dBi then the

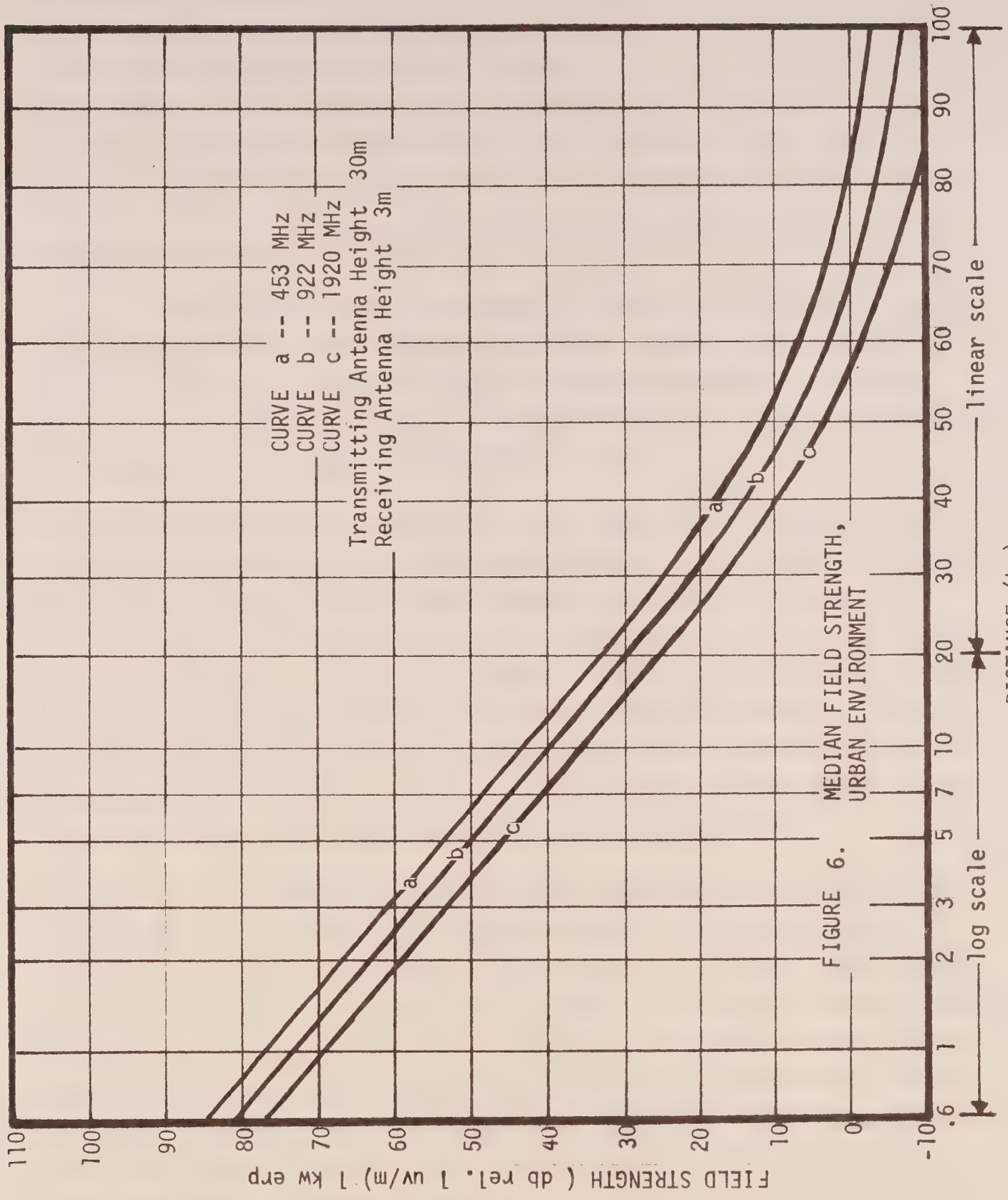

CURVE a -- 453 MHz
CURVE b -- 922 MHz
CURVE c -- 1920 MHz
Transmitting Antenna Height 30m
Receiving Antenna Height 3m
MEDIAN FIELD STRENGTH,
URBAN ENVIRONMENT
FIELD STRENGTH (db rel. 1 uv/m) 1 kw erp
DISTANCE (km)
log scale
linear scale
110
100
90
80
70
60
50
40
30
20
10
0
-10
.6
1
2
3
5
7
10
20
30
40
50
60
70
80
90
100

FIGURE 6.

equivalent received power from an isotropic source would be -144.2 dBW or 3.8×10^{-15} watts. The field power density is this power divided by $(\lambda^2/4\pi)$, the effective area of the isotrope, or 1.09×10^{-13} watts per square meter. This, in turn, can be converted to 6.41 μv/meter, or 16.1 dBu. Add 30 dB to agree with the 1 kW transmitter power used for the curve and we find a maximum distance of 8 kilometers or 5 miles.

Performing the same calculations at 922 MHz and 1920 MHz see Figures 7 & 8.

It can be seen from this that the range is inversely proportional (roughly) to the square root of the ratio of frequencies. However, the number of repeaters required to blanket an area is inversely proportional to the square of the ratio of the range. This boils down to - cut the frequency in half and you cut the number of repeaters in half.

If the terminal is in an automobile it will experience a spread of the spectrum of the signal in the city due to doppler. If it were in a simple deterministic field it would experience merely a shift of frequency by $(2\ v/\lambda)$Hz where v is the velocity of the vehicle relative to the direction of wave propagation. In the city, however, the vehicle is driving through a myriad of reflections of the wave arriving from all directions. Consequently, the power spectrum of a stable signal will be spread so that the -10 dB points are at $\pm 2s/\lambda)$ Hz where s is the speed of the vehicle[6]. At 30 mph and 2 GHz, the minimum bandwidth would then be 360 Hz.

W. R 'Young, Jr[7] measured echoes at various frequencies in New York City. These echoes are a reflection-multipath problem and are not function of frequency. His data shows a 50% probability of a 2 μs echo, a 45% chance of a 3 μs echo and a 30% chance of a 5 μs echo. All these echoes are within 12 dB of the strongest pulse. There appears to be echoes on every trace shown within 10 dB of the strongest pulse, the only variability is when it will come. There is even a 2% chance of a strong echo at 10 μs delay. To allow for strong 10 μs echoes the maximum signalling rate would be less than 50 kilobits. Mesenberg[8] explores the realm of irreducible bit error rates in his article. Assuming a 20 dB signal-to-noise ratio and a 6 dB echo, the bit error rate would be on the order of 3×10^{-3} for noncoherent FSK signalling.

Frequency	453 MHz	922 MHz	1920 MHz
Required received power	-133.2 dBW	-134 dBW	-138 dBW
Receive antenna gain	11 dB	11 dB	11 dB
Equivalent isotrope power	-144.2 dBW	-145 dBW	-149 dBW
Equivalent isotrope power	3.8×10^{-15}	3.16×10^{-15} W	1.26×10^{-15}
Field power density	1.09×10^{-13} W/m^2	3.75×10^{-13} W/m^2	6.5×10^{-13} W/m^2
Field strength	6.4 μV/m	11.9 μV/m	15.6 μV/m
Field strength + 30 dB	46 dBμ	51.5 dBμ	53.9 dBμ
Maximum distance	8 km	5.5 km	3.5 km
Maximum distance	5 mi	3.4 mi	2.2 mi

Figure 7

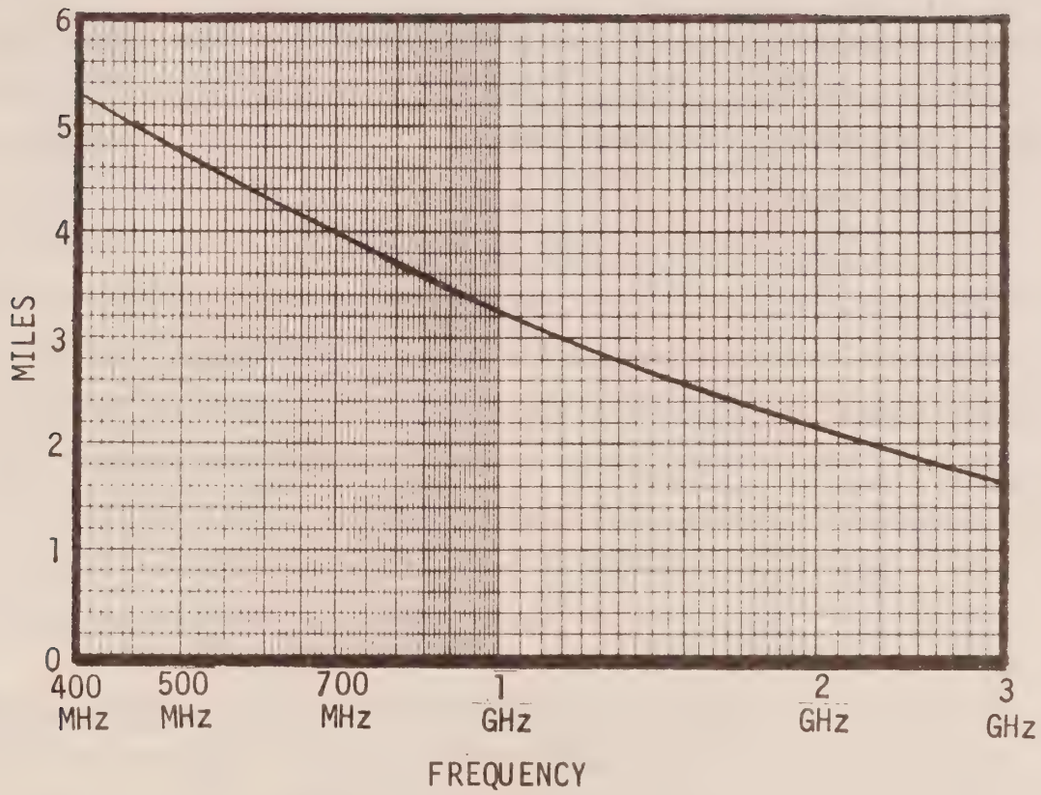


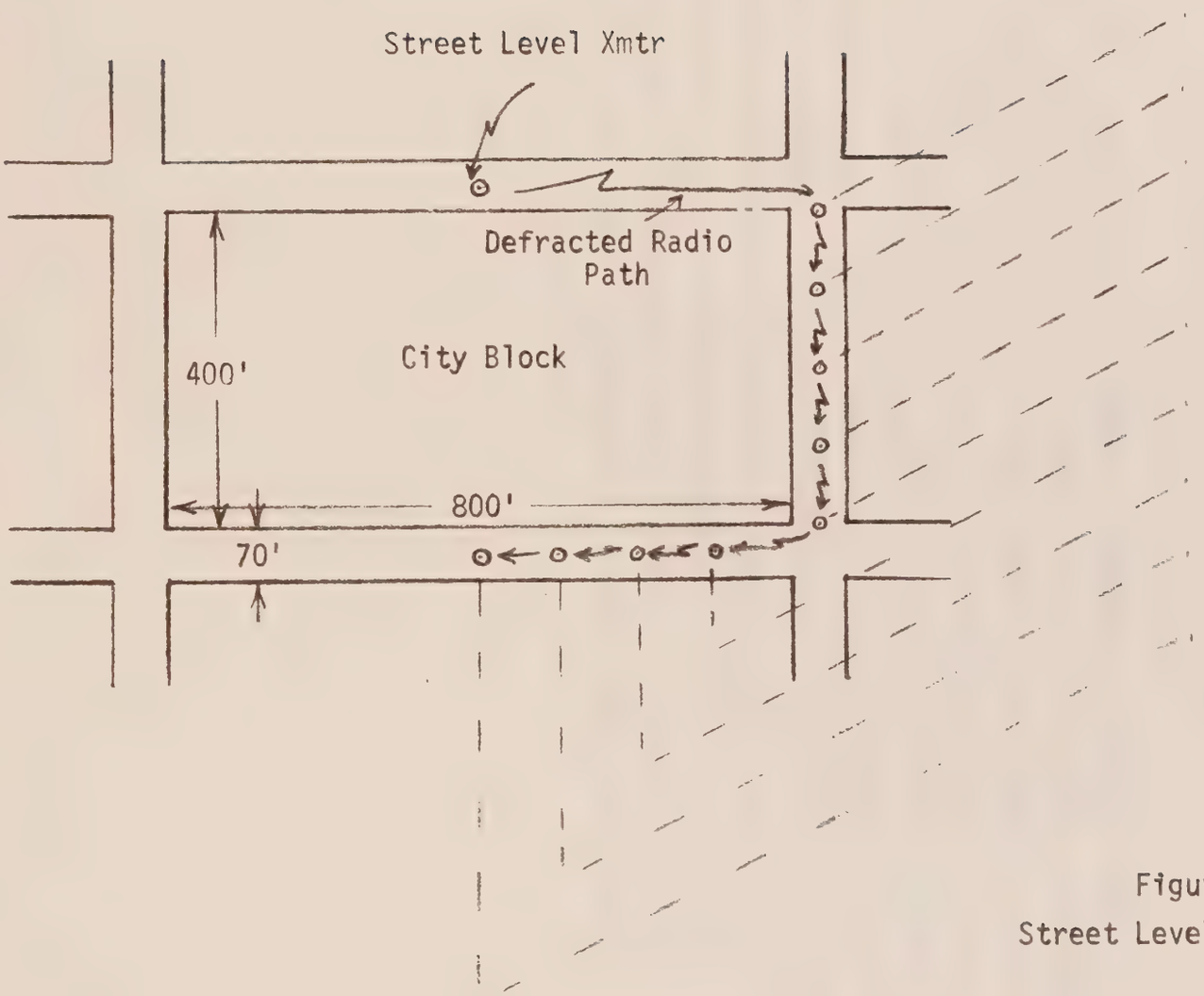
FIGURE 8.
A plot of the maximum distance between a terminal, 1 watt peak power and low height, to a repeater having an 11 dbi gain antenna at 30m height.

Multipath fading is always present in the city with depths of fades being greater than 20 dB. These nulls exist in the standing wave field so a stationary user can move his radio a few feed to avoid the nulls. A mobile user will have to suffer. The nulls are spaced approximately at half wavelength intervals so the fade rate in a moving vehicle is proportional to the frequency.

Considering the very local diffraction effects in a city among tall buildings it is informative to determine the path loss (excluding multipath) around sharp corners. In Figure 9 a "block" geometry is defined as maybe representing a typical situation in a large city. The figure shows a transmitter located at street level in the middle of the block and then successive locations of a receiver. Frequencies of 30, 300, and 3000 MHz are chosen and simple knife edge diffraction around the corners is assumed. The added loss per bend is 20 dB @ 30 MHz, 30 dB @ 300 MHz, and 40 dB @ 3000 MHz. It is doubtful if more than two bends could be tolerated. If the antenna were located at rooftop level, one bend would be involved in getting to the street. It is easy to see where the added 30 dB or more of loss in an urban environment comes from. Obviously the lower the frequency, the better.

Suburban Terminal-to-Repeater. Referring back to Okumura's curves in Figure 6 the field strength in a suburban area is taken from the urban curve for the frequency and distance, then a correction factor is added for frequency correction. This correction factor, 8.5 dB at 500 MHz and increases at 2 dB per octave up through 3 GHz, the limit of their measurements. The effect of the frequency correction curveis to remove the frequency dependence and essentially causes the corrected field strengths to agree with those shown in the CCIR Rec. 370-1. The empirical equation presented in another section applies quite well to suburban locations. Here again, the user antenna is quite low compared to that of the repeater.

Echoes and doppler spreads appear quite frequently in suburban areas as they did in the city. Buildings are more likely to be uniform in size and spacing in the suburbs which makes the echoes easier to explain but no easier to avoid.[9]



Street Level Receivers Propagation Loss Values (DB) 30 MHz	300 MHz	3000 MHz
51	71	91
60.5	89.5	120.5
66	96	126
70	100	130
73	103	133
87	126	167
91	131	171
93.5	133.5	173.5
95	135	175

Figure 9
Street Level Signal Defraction

Open Area Terminal-to-Repeater. Nirvana at last! Multipath fading and echoes disappear, field strengths get stronger, coverage ranges get longer. It is a pity that radio propagation is best in places where there is nobody to talk to. Again, referring to Okumura's curves in Figure 6 , he provides another frequency correction factor to values taken from the curves of Figure 6 . Here the correction factor is 21.5 to 26.5 dB at 500 MHz depending on how smooth the terrain is, and increases at 3 dB per octave. Very smooth terrain gets the higher factor where the lower factor is for gently rolling hills of 20 meters knoll to valley. A sample calculation might prove interesting here. Again, choosing 1920 MHz, we'll use 23.5 for our 500 MHz correction factor, so we have a correction factor at 1920 MHz of 29.33 dB. See Figure 10. Compare this 16 miles to the 2.2 miles covered in the city by the same calculations.

CONCLUSIONS

The limiting case for the terminal-repeater link is the urban location. The range will be short (generally less than 3 miles) and with omnidirectional antennas at both ends, multipath will limit the signalling rate plus the flexibility of location, as well as range. The frequency should be as low as possible. If signalling rates in excess of about 50 kilobits is contemplated, consideration should be given toward using azimuthally directional antennas on the repeaters. The number of repeaters necessary to blanket an area is roughly proportional to frequency. Suburban repeater-to-repeater links are similarly limited without the problem of location variability and restricted range. The maximum range is still in the 6-10 mile area and directional antennas will be required to handle signalling rates of more than a couple of hundred kilobits.

Freq.	1920 MHz
Required received power	-138 DBW
Receive antenna gain	11 DB
Equivalent isotrope power	-149 DBW
Equivalent isotope power	1.26×10^{-15} W
Field power density	6.48×10^{-13} W/M^2
Field Strength	15.6 uV/M
Field strength +30 DB	53.9 DBU
Open Area Correction factor	29.3
Equivalent Urban field strength	24.6 DBU
Maximum Distance	27 KM
Maximum Distance	16 MI

Figure 10

REFERENCES

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